US009117963B2

(12) United States Patent
Kim et al.

(10) Patent No.: US 9,117,963 B2
(45) Date of Patent: Aug. 25, 2015

(54) SOLAR CELL

(75) Inventors: **Sungjin Kim**, Changwon-si (KR); **Taeyoung Kwon**, Changwon-si (KR); **Seongeun Lee**, Changwon-si (KR); **Gyeayoung Kwag**, Changwon-si (KR)

(73) Assignee: **LG ELECTRONICS INC.**, Seoul (KR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 281 days.

(21) Appl. No.: **13/312,028**

(22) Filed: **Dec. 6, 2011**

(65) **Prior Publication Data**

US 2012/0138141 A1 Jun. 7, 2012

(30) **Foreign Application Priority Data**

Dec. 6, 2010 (KR) 10-2010-0123692

(51) **Int. Cl.**

H01L 31/042 (2014.01)
H01L 31/18 (2006.01)
H01L 31/0224 (2006.01)

(52) **U.S. Cl.**

CPC ***H01L 31/1804*** (2013.01); ***H01L 31/022433*** (2013.01); *Y02E 10/547* (2013.01)

(58) **Field of Classification Search**

CPC H01L 31/00–31/078; Y02E 10/50–10/60
USPC 136/243–265
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2007/0186968	A1*	8/2007	Nakauchi et al.	136/244
2010/0018562	A1*	1/2010	Kurahashi et al.	136/244
2011/0247688	A1*	10/2011	Yoon et al.	136/256
2011/0277835	A1*	11/2011	Masson et al.	136/256

FOREIGN PATENT DOCUMENTS

KR WO2010030109 * 3/2010

* cited by examiner

Primary Examiner — Bach Dinh

(74) *Attorney, Agent, or Firm* — Birch, Stewart, Kolasch & Birch, LLP

(57) **ABSTRACT**

A solar cell includes a photoelectric conversion layer and a front electrode on the photoelectric conversion layer. The front electrode includes a bus bar electrode; at least one first finger electrode directly connected to the bus bar electrode; a plurality of connecting electrodes extending from the bus bar electrode and having a width smaller than a width of the bus bar electrode, wherein the plurality of connecting electrodes includes portions that are spaced apart from each other to form a space therebetween; at least one second finger electrode connected to at least one of the plurality of connecting electrodes; and an auxiliary electrode formed at the space between the portions of the plurality of connecting electrodes.

16 Claims, 7 Drawing Sheets

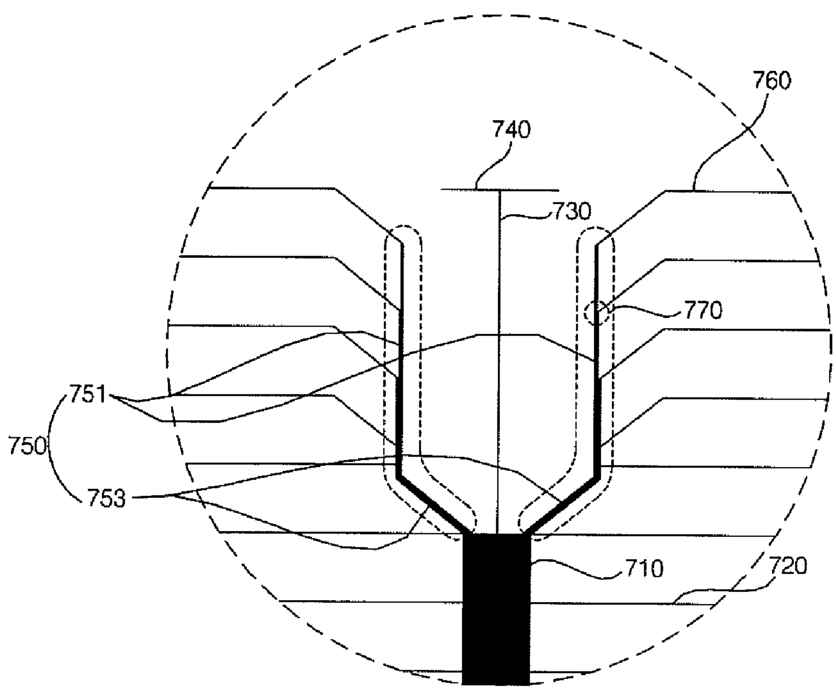


FIG. 1

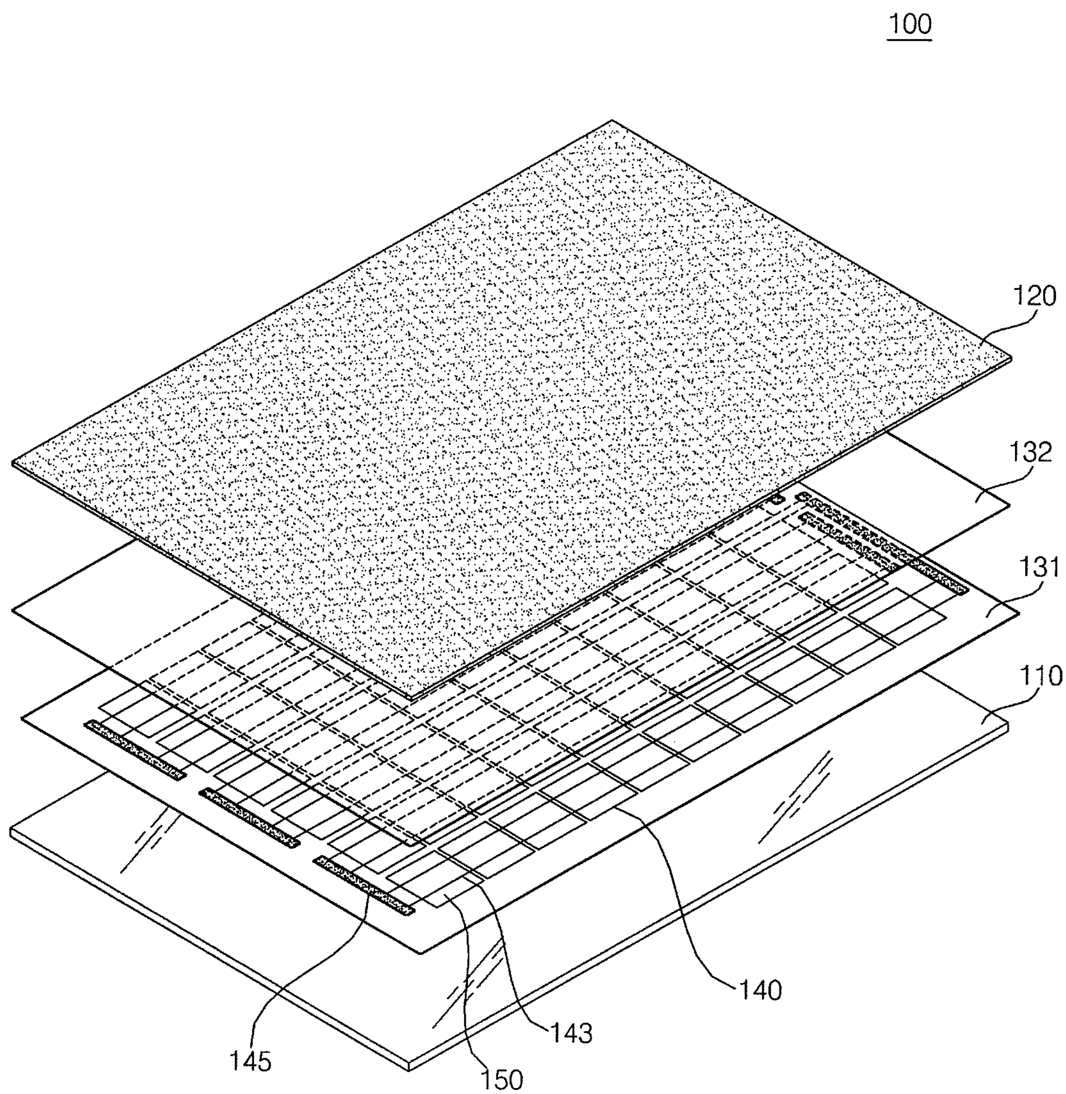


FIG. 2

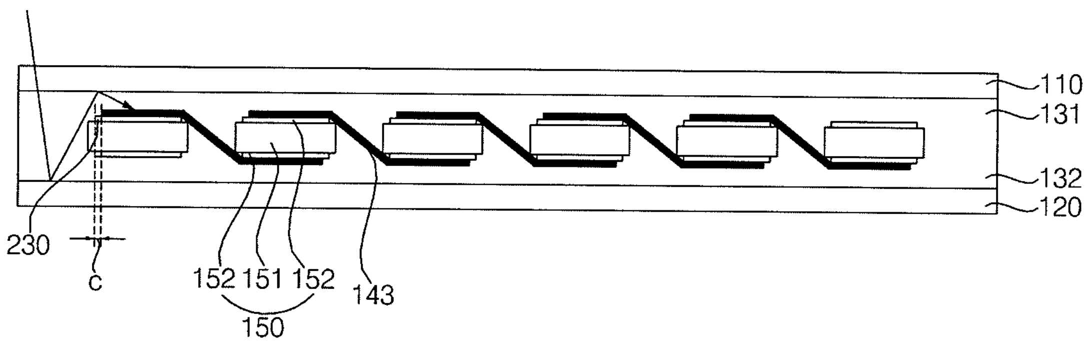


FIG. 3

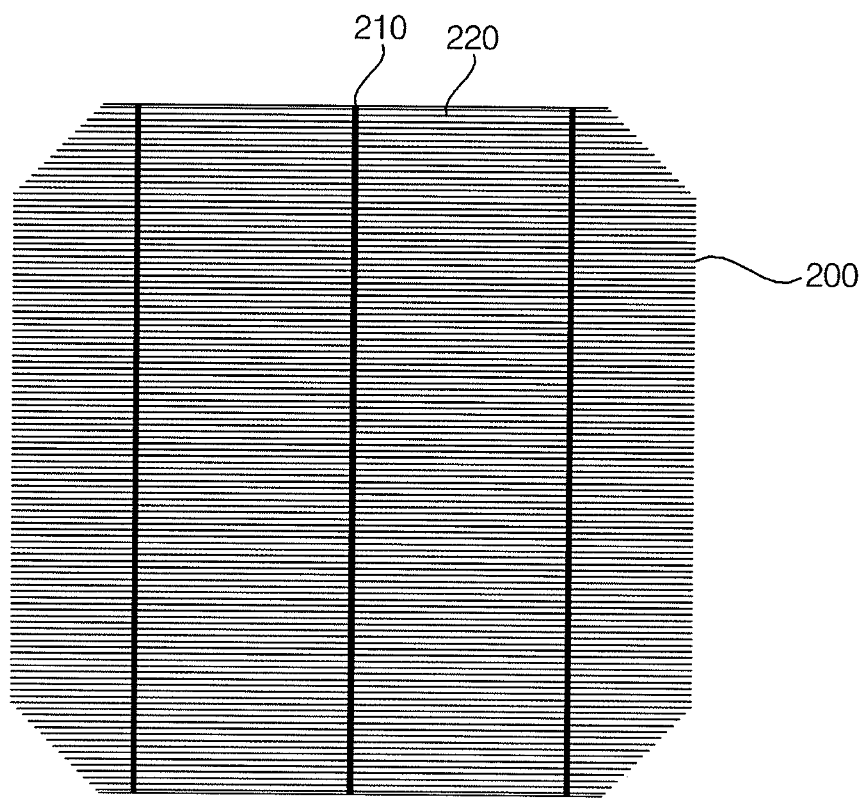


FIG. 4

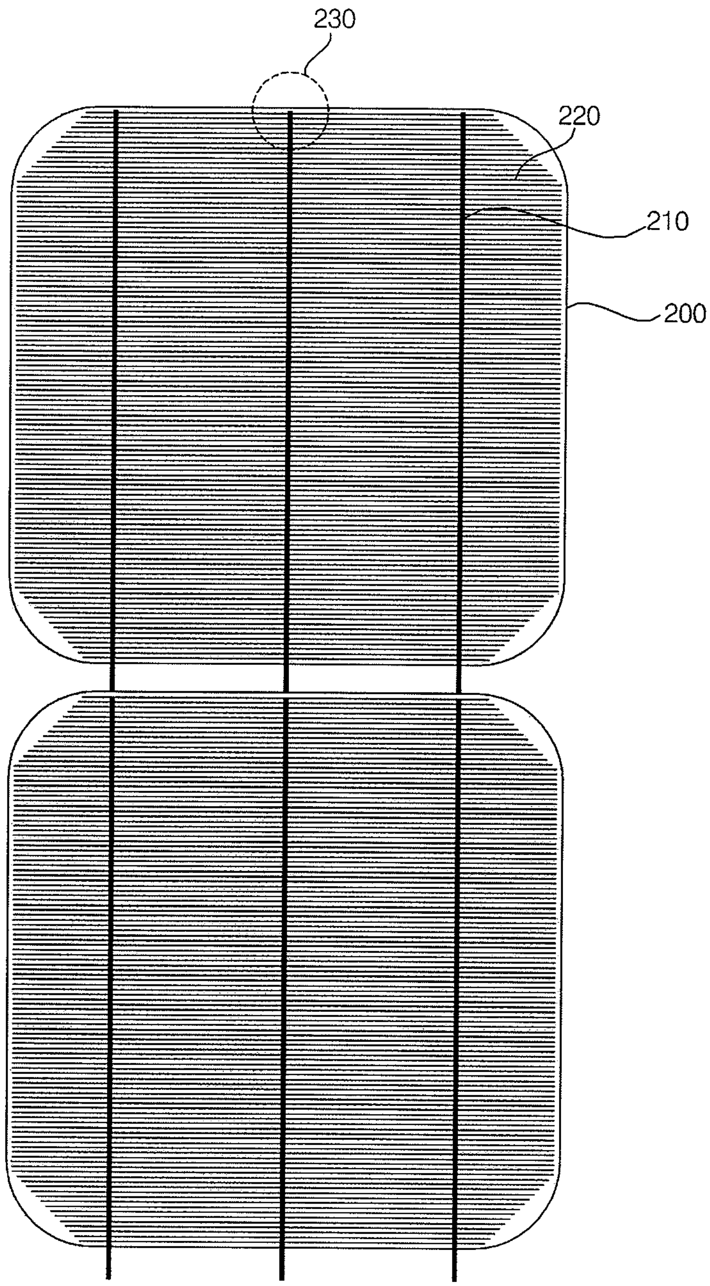


FIG. 5

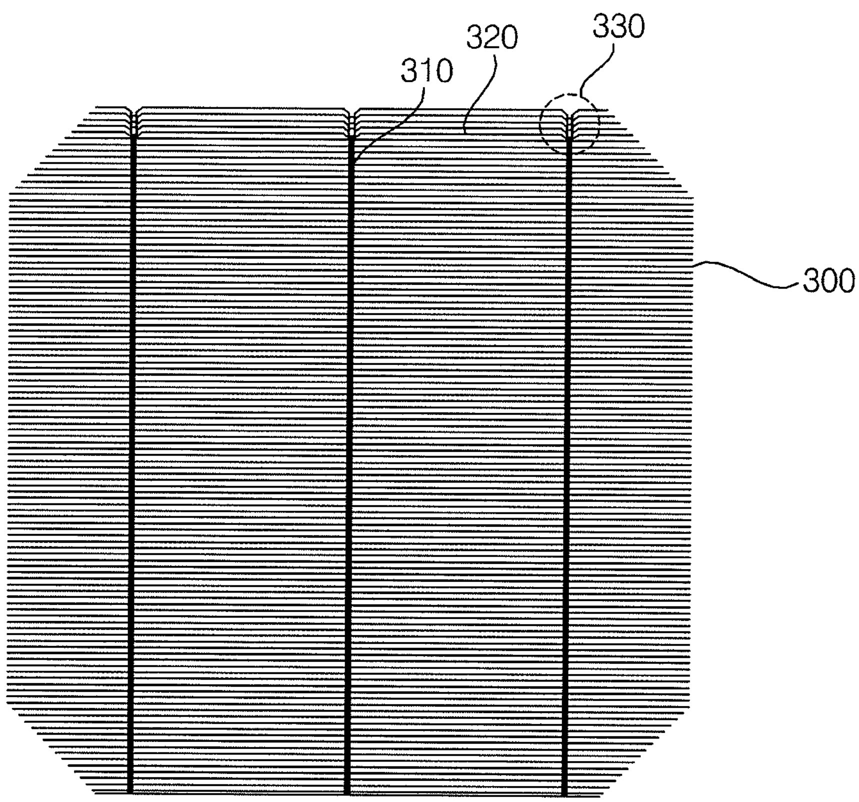


FIG. 6

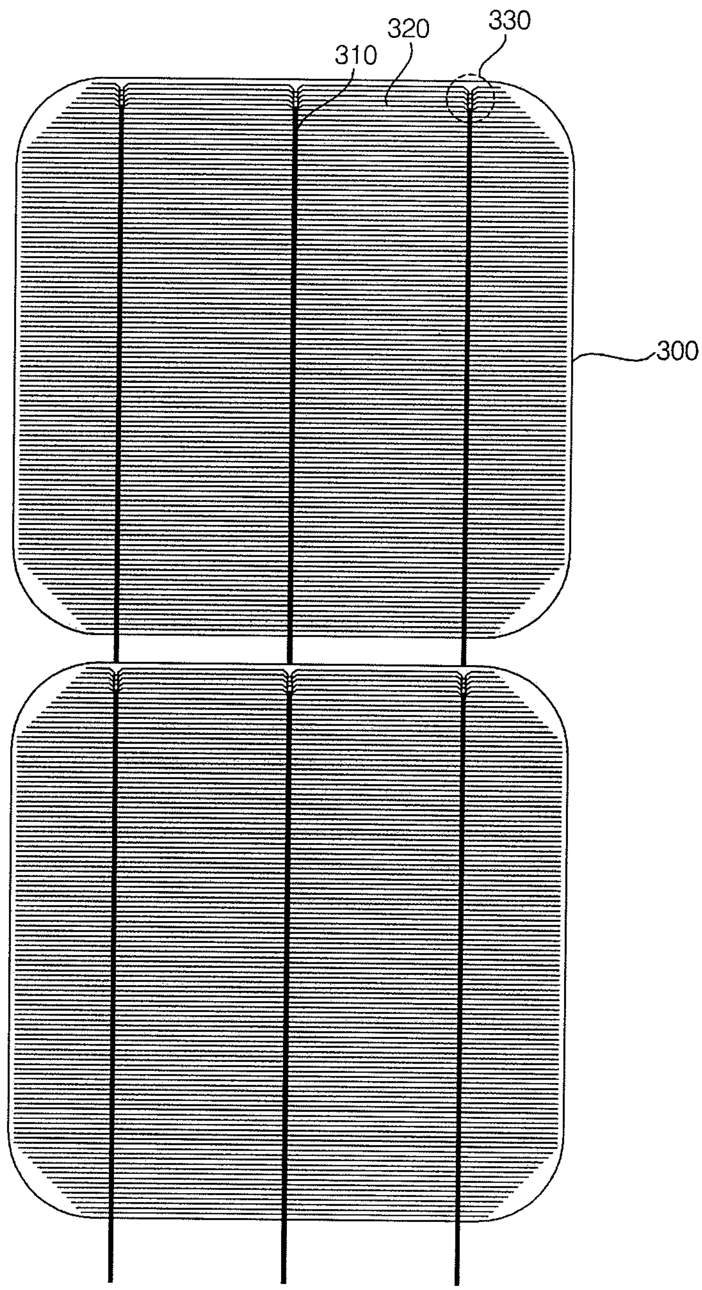


FIG. 7

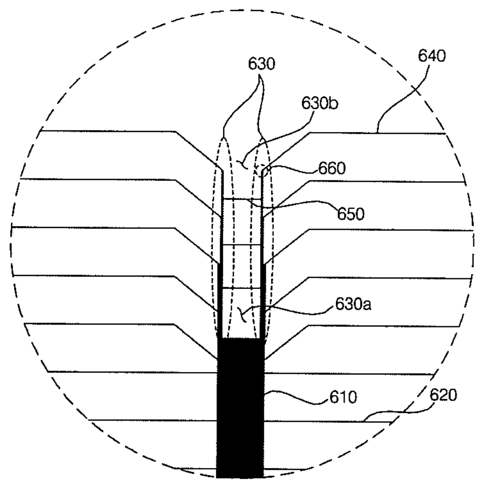

630
640
630b
660
650
630a
610
620

FIG. 8

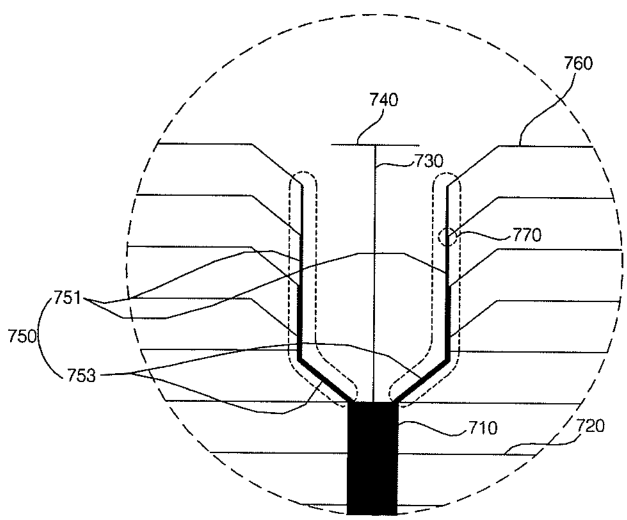
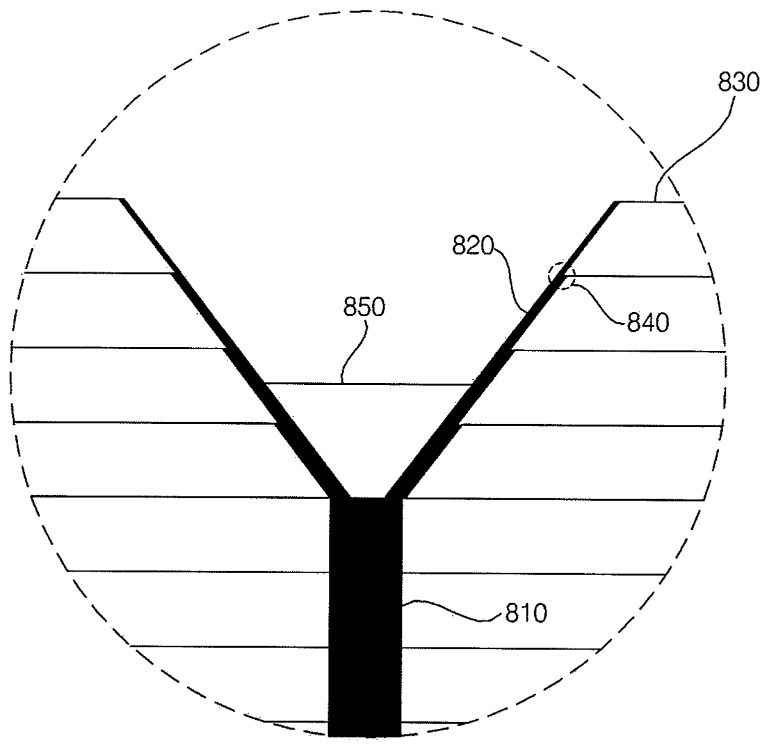

760
740
730
770
751
750
753
710
720

FIG. 9



SOLAR CELL

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority to and the benefit of Korean Patent Application No. 10-2010-0123692, filed on Dec. 6, 2010 in the Korean Intellectual Property Office, the disclosure of which is incorporated herein by reference.

BACKGROUND

1. Field of the Invention

Embodiments of the invention relate to a solar cell, and more particularly, to a solar cell having an improved electrode structure.

2. Description of the Related Art

Recently, as conventional energy resource such as petroleum and coal are expected to be exhausted and the environment is seriously polluted, significance of development in next-generation clean energy is increasing. Also, demand for renewable energy is increasing in the 21st century, and thus, interest in solar cells is also increasing. Solar cells do not pollute the environment, use a practically infinite energy resource, and can be used semi-permanently. Thus, solar cells are expected to be an energy source for solving future energy problems.

Solar cells can be largely classified into a crystalline silicon solar cell, a thin-film solar cell, and a dye-sensitized solar cell. The cost of the crystalline silicon solar cell has increased due to a short supply of a silicon raw material and a shortage of a silicon substrate induced by installing a large number of solar cell systems in recent years. For this reason, a thin-film silicon solar cell, a dye-sensitized solar cell, and a plastic solar cell are in the spotlight because their cost is low, their consumption of the raw material is less, and their supply of the raw material is stable. Despite the low cost, however, low conversion efficiency and short lifetime of the solar cells, such as the thin-film silicon solar cell, the dye-sensitized solar cell, and the plastic solar cell, are blocking the industrialization thereof. Therefore, recent studies about the solar cells are focused on techniques for improving the efficiency of the solar cells. To improve the efficiency of the solar cells, a structure or a pattern of a front electrode formed on a light incident surface of the solar cell needs to be improved.

SUMMARY OF THE INVENTION

Embodiments of the present invention are directed to a solar cell including a front electrode pattern that is able to minimize a loss of a light incident area.

A solar cell according to an embodiment of the invention includes a photoelectric conversion layer and a front electrode on the photoelectric conversion layer. The front electrode includes a bus bar electrode; at least one first finger electrode directly connected to the bus bar electrode; a plurality of connecting electrodes extending from the bus bar electrode and having a width smaller than a width of the bus bar electrode, wherein the plurality of connecting electrodes includes portions that are spaced apart from each other to form a space therebetween; at least one second finger electrode connected to at least one of the plurality of connecting electrodes; and an auxiliary electrode formed at the space between the portions of the plurality of connecting electrodes.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an exploded perspective view of a solar cell according to an embodiment of the invention;

FIG. **2** is a schematic cross-sectional view of the solar cell shown in FIG. **1**;

FIG. **3** is a plan view of a front electrode formed on a front portion of a typical solar cell.

FIG. **4** is a partial view of a solar cell module formed by combining the solar cells shown in FIG. **3**;

FIG. **5** is a plan view of a front electrode formed on a front portion of a solar cell according to an embodiment of the invention;

FIG. **6** is a partial view of a solar cell module formed by combining solar cells according to the embodiment of the invention; and

FIGS. **7** to **9** are plan views of finger electrodes and bus bar electrodes of the solar cell shown in FIG. **5**.

DETAILED DESCRIPTION OF THE EMBODIMENTS

In the following description, it will be understood that when a layer or film is referred to as being "on" another layer or substrate, it can be directly on the other layer or substrate, or intervening layers may also be present. Further, it will be understood that when a layer is referred to as being "under" another layer, it can be directly under the other layer, and one or more intervening layers may also be present. In the figures, the dimensions of layers and regions are exaggerated or schematically illustrated, or some layers are omitted for clarity of illustration. In addition, the dimension of each part as drawn may not reflect an actual size.

Hereinafter, embodiments of the invention will be described with reference to the accompanying drawings.

FIG. **1** is an exploded perspective view of a solar cell according to an embodiment of the invention, and FIG. **2** is a schematic cross-sectional view of the solar cell shown in FIG. **1**.

Referring to FIGS. **1** and **2**, a solar cell module **100** according to an embodiment of the invention includes a plurality of solar cells **150**, a plurality of ribbons **143** for connecting the plurality of solar cells **150**, at least one bus ribbon **145** for connecting the ribbons **143**, a first sealing film **131** and a second sealing film **132** for sealing the solar cells **150** on both sides, a front substrate **110** for protecting a light incident surface of the solar cells **150**, and a rear substrate **120** for protecting a rear surface of the solar cells **150**.

Each solar cell **150** is a semiconductor device for converting solar energy to electric energy. Referring to FIG. **2**, the solar cell **150** includes a photoelectric conversion layer **151**, electrode layers **152** formed on at least one surface of the photoelectric conversion layer **151**, and the ribbons **143** for connecting the solar cells **150**. At an interface surface of the electrode layer **152** and the ribbon **143**, a eutectic mixture may be formed. In FIG. **2**, the electrode layers **152** include a front electrode layer and a rear electrode layer as an example. However, embodiments of the invention are not limited thereto. Thus, the electrode layers **152** may be formed only at the rear surface of the photoelectric conversion layer **151** in other embodiments of the invention. In this instance, the ribbon **143** connects the electrode layers **152** formed on the rear surfaces (or the rear sides) of two solar cells **150** adjacent to each other among the solar cells **150**.

The photoelectric conversion layer **151** may include silicon, a compound semiconductor, or a tandem structure. In the photoelectric conversion layer **151**, a P-N junction is formed, and thus, the electric energy is generated by a photoelectric effect when light, such as sun light, is incident.

The electrode layer **152** connected to a p-type layer **123** may be formed, for example, by coating a paste for an electrode including aluminum, silica, binder, and so on, on one surface on the photoelectric conversion layer **151** and heat-treating the paste. During a firing process, organic materials and a solvent included in the coated paste are removed. Upon the heat-treating, the aluminum for forming the electrode is diffused through the rear surface of the photoelectric conversion layer **151** to form a back surface field at the interface of the electrode layer **152** and the photoelectric conversion layer **151**.

According to embodiments of the invention, the solar cell **150** includes the ribbon **143**, and the ribbon **143** is adjacent to (or attached to) one surface of the electrode layer **152**. At the interface of the electrode layer **152** and the ribbon **143**, the eutectic matrix may be formed. At least an outer surface of the ribbon **143** includes at least one of Cu, Nu, Ca, Sn, Zn, In, and Sb for a eutectic bonding.

A front surface of the photoelectric conversion layer **151** may include a textured surface. Performing texturing of the front surface forms a pattern of convex-concave shapes or an uneven surface. Since the surface of photoelectric conversion layer **151** has a large roughness because of the textured surface, the reflectance of the incident light decreases and the photoelectric conversion layer **122** absorbs more light. That is, the light loss can be reduced.

Referring again to FIG. **1**, the ribbon **143** may include two lines attached to an upper portion and a lower portion of the solar cells **150** in order to connect the solar cells **150**. The solar cells **150** electrically connected by the ribbon **143** form a string **140**. A plurality of strings **140** adjacent to each other may be arranged to form a plurality of columns.

The bus ribbon **145** is positioned where the string **140** is not formed, and is connected to the ribbon **143**. The bus ribbon **145** may be connected to a lead line that is connected to a junction box for charging and discharging the electric energy and for preventing countercurrent.

Also, the bus ribbon **145** alternately connects both ends of the ribbons **143** of the strings **140**, thereby electrically connecting the strings **140**. The bus ribbon **145** may be arranged in a row direction at the both ends of the strings **140** arranged to form the plurality of columns. The strings **140** for forming the plurality of columns may be formed between the first sealing film **131** and the second sealing film **132**.

The first sealing film **131** may be positioned on the light incident surface of the solar cells **150**, and the second sealing film **132** may be positioned on the rear surface of the solar cells **150**. The first sealing film **131** and the second sealing film **132** may be attached by a lamination method. The first sealing film **131** and the second sealing film **132** block moisture and oxygen that may be harmful to the solar cells **150**.

In addition, the first sealing film **131** and the second sealing film **132** chemically combine elements of the solar cells **150** to each other. The first sealing film **131** and the second sealing film **132** may include an ethylene-vinyl acetate (EVA) copolymer resin, polyvinyl butyral, an ethylene-vinyl acetate having a partial oxide, a silicone resin, an ester-based resin, and/or an olefin-based resin.

The front substrate **110** is positioned on the first sealing film **131** so that the sun light can penetrate therethrough. The front substrate **110** may be formed of a transparent material, such as a tempered glass, in order to protect the solar cells **150** from an external impact. Specifically, the front substrate **110** may be a low-iron tempered glass in order to reduce or prevent the reflection of the sun light and to improve the transmissivity of the sun light.

The rear substrate **120** protects the solar cells **150** at the rear surface thereof and may be waterproof, may insulate, or may filter ultraviolet light. The rear substrate **150** may be a TPT (Tedlar/PET/Tedlar) type. However, embodiments of the invention are not limited thereto. In addition, the rear substrate **120** may include a material having a high reflectivity property in order to reuse the sun light incident through the front substrate **110**, or include a material of a transparent property that allows the sun light to be incident.

FIG. **3** is a plan view of a front electrode formed on a front portion of a typical solar cell, and FIG. **4** is a partial view of a solar cell module formed by combining the solar cells shown in FIG. **3**. A solar cell **200** shown in FIGS. **3** and **4** has a typical structure. The FIGS. **3** and **4** show a front surface of the solar cell **200** where finger electrodes **220** and bus bar electrodes **210** are formed.

FIG. **3** shows a typical pattern of the front electrode. FIG. **3** shows the pattern as including the finger electrodes **220** that are densely positioned and the bus bar electrodes **210**. However, such is just one example pattern of the front electrode. Thus, the front electrodes having various patterns are disclosed.

The front electrode having metal is formed on the front surface of the solar cell **200** in order to collect charges generated by the incident sun light. The front electrode includes grids that are generally referred to as the finger electrodes **220** or finger metal lines, and the bus bar electrodes **210** having a bar shape and being electrically connected to the grids as main electrodes. When the solar cell **200** generates electric energy, the electrons or the holes are collected by the bus bar electrodes **210** via the finger electrodes **220**, and then, are collected by the ribbon **145**.

However, since the sun light is reflected by the front electrode, and the sun light cannot penetrate the front electrode, the front electrode generates a shading loss and reduces the efficiency of the solar cell. Thus, in order to reduce the shading loss, an area of the front electrode that covers the light incident surface of the solar cell needs to be decreased. However, if the width of the finger electrodes is decreased to reduce the contact area and the shading loss, resistance of the finger electrodes may be increased due to the reduction of the cross-sectional area of the electrodes. Thus, electric loss may be increased.

That is, the front electrode on the front surface of the solar cells **200** is needed to have an optimal structure for having a high opening ratio in order to absorb more light and for minimizing the resistance and the shading loss. Typically, the width and the area of the finger electrodes **220** may be adjusted in order to improve the efficiency of the solar cells **200** by reducing the shading loss. However, the finger electrodes **220** basically have a width larger than 100 μm, and thus, the adjustment of the width and the area of the finger electrodes **220** is limited. In addition, a lithography method and a laser transfer method have been proposed in order to reduce the width of the finger electrodes **220**. However, the manufacturing cost of such methods may be high.

For example, the bus bar electrodes **210** of the solar cell **200** are positioned to have a predetermined distance (about 2~3 mm) from edges of the solar cell **200**, and thus, the bus bar electrodes **210** have a length of about 153 mm in a solar cell **200** having a wafer size of 156 mm. Further, the ribbon **143** connecting the solar cells and being attached thereto during manufacturing of a solar cell module have a predetermined distance (C of FIG. **2**; about 2 mm) from an end of the bus bar electrode **210**. Accordingly, the ribbon **143** is not attached to the solar cell at a portion **230** of the bus bar electrodes **210**, and the portion **230** is a loss area for reducing the light incident area.

FIG. **5** is a plan view of a front electrode formed on a front portion of a solar cell according to an embodiment of the invention, and FIG. **6** is a partial view of a solar cell module formed by combining solar cells according to the embodiment of the invention. The solar cell **300** shown in FIG. **5** according to an embodiment of the invention includes finger electrodes **320** and bus bar electrodes **310** having a structure different from those of the solar cells **200** of FIG. **4**. In the solar cell according to this embodiment of the invention, the bus bar electrodes **310** have a shape for reducing loss of the light incident area.

As shown in FIG. **5**, the bus bar electrode **310** is shorter than a typical bus bar electrode. That is, while the typical bus bar electrode is formed across essentially an entire light incident surface of the solar cell from one end (an upper end) to an opposite end (a lower end), an upper portion of the bus bar electrode **310** is formed differently (e.g., not formed or partially removed) in the embodiment of the invention. Thus, the sun light can penetrate the upper portion of the bus bar electrode **310** where the ribbon is not connected. Accordingly, the light incident area can increase, compared to a typical solar cell. The improved structure of the shapes of the bus bar electrodes **310** and the finger electrodes **320** are shown in FIGS. **7** to **9**.

FIGS. **7** to **9** are plan views of finger electrodes and bus bar electrodes of the solar cell shown in FIG. **5**. That is, FIGS. **7** to **9** are enlarged views of portions having shapes of the bus bar electrodes **310** and the finger electrodes **320** of an improved structure. Referring to FIG. **7**, finger electrodes **620** and **640** are connected to a bus bar electrode **610** through connecting electrodes **630**. The finger electrodes **620** and **640** include first finger electrodes **620** and second finger electrodes **640**. The first finger electrodes **620** are directly connected to the bus bar electrode **610**, and the second finger electrodes **640** are connected to the bus bar electrode **610** through the connecting electrodes **630**. Therefore, the second finger electrodes **640** have intersections **660** with the connecting electrodes **630**. The second finger electrodes **640** are positioned at the upper portion of the solar cell, that is, at the portion where the part of the bus bar electrode **610** is not formed or is removed.

Referring to FIG. **7**, the bus bar electrode **610** and the connecting electrodes **630** are vertically formed (or formed parallel to each other), and the first finger electrodes **620** and the second finger electrodes **640** are horizontally formed (or formed parallel to each other). Thus, the bus bar electrode **610** and the first finger electrodes **620** intersect, and the connecting electrodes **630** and the second finger electrodes **640** have the intersections **660**. The connecting electrodes **630** have a width smaller than that of the bus bar electrode **610**, and thus, the area of the connecting electrodes **630** covering the light incident surface of the solar cell is small. Thus, compared to the bus bar electrode **610**, the connecting electrodes **630** reduce the area generating the shading loss. The connecting electrodes **630** are formed at one end of the bus bar electrode **610** (specifically, the portion where the ribbon **143** is not attached to the bus bar electrode **610**). Accordingly, the light incident surface can increase at the portion where the ribbon **143** is not attached.

Also, a portion of the second finger electrode **640** adjacent to the intersection **660** with the connecting electrode **630** may be bent (or inclined) at a predetermined angle. Thus, a path from the second finger electrode **640** to the connecting electrodes **630** can decrease. Accordingly, the shading loss can be reduced, and a metal paste used for forming the connecting electrodes **630** and the second finger electrodes **640** can also decrease. In this instance, when the portion of the second finger electrode **640** has the angle of 45 degrees with the connecting electrodes **630**, the path from the second finger electrode **640** to the connecting electrodes **630** can be minimized, compared with other angles. Considering a tolerance (or margin of error), the angle between the second finger electrode **640** and the connecting electrode **630** may be in a range of about 40 to about 50 degrees. Other angles may be used, including an angle of 90 degrees.

In addition, the width of the connecting electrode **630** may be changed at some portions. The plurality of the second finger electrodes **640** (that is, two or more second finger electrodes **640**) are connected to one connecting electrode **630**. Thus, when the connecting electrode **630** is uniform, the internal resistance of the connecting electrode **630** increases as the number of the second finger electrodes **640** connected to the connecting electrode **630** increase. The number of the intersections **660** of the connecting electrode **630** with the second finger electrodes **640** decreases as the distance from the bus bar electrode **610** increases. That is, in order to achieve uniform resistance, the connecting electrode **630** may have a cross section gradually decreasing as the distance from the bus bar electrode **610** increases. In this instance, the connecting electrode **660** has the cross section varying at each of the intersections **660** of the connecting electrodes **630** and the second finger electrodes **640**. In embodiments of the invention, a thickness of the connecting electrodes **630** may increase based on the number of connections **660** made with the second finger electrodes **640** in going from the edge of the solar cell to the bus bar electrode **610**.

However, embodiments of the invention are not limited thereto. Thus, if some amount of shading loss by the connecting electrodes **630** is acceptable, the connecting electrodes **630** may have a uniform cross section though its entire length. In this instance, the connecting electrodes **630** may have a cross section (which may be predetermined) in a range that the internal resistance of the connecting electrodes **630** does not exceed a predetermined value.

In the embodiment of the invention, the plurality of the second finger electrodes **640** are connected to one connecting electrodes **630**. Thus, when a short-circuit is generated at any one portion of the connecting electrodes **630**, the electrons-flowing path through the second finger electrodes **640** is blocked. Thus, in order to address the above instance, the plurality of the connecting electrodes **630** (that is, two or more connecting electrodes **630**) may be formed. The plurality of connecting electrodes **630** may be formed apart from each other to form a space therebetween. Thus, a space between the connecting electrodes **630** may have an opening **630***a*, or may have a portion **630***b* which is open toward an outside. At the space between the connecting electrodes **630**, a bridge electrode **650** connecting the connecting electrodes **630** may be formed. Accordingly, when the short-circuit is generated at one connecting electrode **630**, the carriers flowing through the second finger electrodes **640** connected to the one connecting electrodes **630** can flow toward the bus bar electrode **610** via the bridge electrode **650** and another connecting electrode **630**, so that ultimately, the second finger electrodes **640** connected to the connecting electrode **630** with the short-circuit can be electrically connected to the bus bar electrode **610**. That is, the bridge electrode **650** is formed at the space disposed between the adjacent connecting electrodes **630** as an auxiliary electrode. Thus, the problem due to the short-circuit in the connecting electrodes **630** can be addressed.

In this instance, the bridge electrode **650** may be connected to portions of the connecting electrodes **630** that are positioned between two adjacent second finger electrodes **640**. Thereby, a problem due to a plurality of electrodes being concentrated at one portion can be addressed. That is, the electrically connected portions can be dispersed, and thus, safety and stability can be improved. In the embodiment of the invention, the connecting electrodes **630** having widths smaller than that of the bus bar electrode **610** are formed at one end of the bus bar electrode **610** where the ribbon **143** is not attached, and thus, an area of a light incident surface can increase at a portion where the ribbon **143** is not attached. Specifically, light can be incident through the opening **630***a* defined by the bus bar electrode **610**, the connecting electrodes **630**, and the bridge electrode **650**, or the portion **630***b* open towards the outside between the connecting electrodes **630**, and thus, the area of the light incident surface can increase.

In embodiments of the invention, the bridge electrode **650** and the connecting electrodes **630** may have a lattice arrangement. Also, when a plurality of bridge electrodes **650** are used, lengths of the plurality of bridge electrodes **650** may be the same. Additionally, increase in the cross section of the connecting electrode **630** may produce steps that face towards the outside (i.e., face towards the second finger electrodes **640**).

FIG. **8** is a plan view of a front electrode according to another embodiment of the invention. As shown in FIG. **8**, the front electrode includes a bus bar electrode **710**, an auxiliary bus bar electrode **730**, connecting electrodes **750**, first finger electrodes **720**, second finger electrodes **760**, and a third finger electrode **740**. In this instance, the first finger electrodes **720** are directly connected to the bus bar electrode **710** to have intersections therebetween. The auxiliary bus bar electrode **730** is extended from the bus bar electrode **710** and has a width smaller than the bus bar electrode **710**. The third finger electrode **740** is connected to the auxiliary bus bar electrode **730** and is nearer to an edge of the solar cell than the first and second finger electrodes **720** and **760**. The third finger electrode **740** is farthest from the bus bar electrode **710** as compared to the first and second finger electrodes **720** and **760**. Since the auxiliary bus bar electrode **730** is connected to the third finger electrode **740** that are fewer in number than the first and second finger electrodes **720** and **760**, the auxiliary bus bar electrode **730** can have a width smaller than a width of the first bus bar **710**. In embodiments of the invention, the auxiliary bus bar electrode **730** may extend parallel to the bus bar electrode **710**, but may alternatively extend non-parallel to the bus bar electrode **710**. Also, a plurality of auxiliary bus bar electrodes **730** may be connected to the bus bar electrode **710**. The third finger electrode **740** may be connected to the auxiliary bus bar electrode **730** in a non-perpendicular manner in other embodiments.

The embodiment of the invention includes the auxiliary bus bar electrode **730** and the third finger electrodes **740** disposed at a space between the connecting electrodes **750** as auxiliary electrodes. That is, a surface area available for light incidence can be sufficiently procured by the space between the connecting electrodes **750**, and the current generated at the space between the connecting electrodes **750** can be collected by the auxiliary bus bar electrode **730**. The third finger electrodes **740** connected to the bus bar electrode **730** allows the current generated at the space between the connecting electrodes **750** to be collected even more. That is, in the embodiment of the invention, the current generated at the portion between the connecting electrodes **750** can be effectively collected while surface available for light incidence can be sufficiently procured at the portion where the ribbon **143** is not attached.

The auxiliary bus bar electrode **730** and the third finger electrodes **740** may be disposed apart from the connecting electrodes **750** and the second finger electrodes **760** so that the current collected by the auxiliary bus bar electrode **730** and the third finger electrodes **740** can flow to the bus bar electrode **710** through a shortest path.

In FIG. **8**, a single third finger electrode **740** is shown as an example. However, embodiments of the invention are not limited thereto. For example, some finger electrodes that are disposed far away from the bus bar electrode **710** may be the third finger electrodes **740**. Also, in FIG. **8**, the third finger electrode **740** and the auxiliary bus bar electrode **730** form a T shape. In another embodiment of the invention, the third finger electrode **740** may be bent at an intersection with the auxiliary bus bar electrode **730**, and thus, the third finger electrode **740** and the auxiliary bus electrode **730** may have a Y shape. In this instance, the path from the third finger electrodes **740** to the auxiliary bus bar electrode **730** can be reduced even more. Also, the third finger electrode **740** and the auxiliary bus electrode **730** may have a cross shape (+).

The second finger electrodes **760** have intersections with the connecting electrodes **750**, and are connected to the bus bar electrode **710** through the connecting electrodes **750**. The connecting electrodes **750** include a first region **751** having an intersection with the second finger electrodes **760** and a second region **753** connecting the second finger electrodes **760** and the bus bar electrode **710**. The first region **751** of the connecting electrodes **750** is apart from the bus bar electrode **710**, and the second region **753** is bent toward the bus bar electrode **710**. In this instance, when the second region **753** has an angle of 45 degrees with the first region **751** (as in the instance that a distance between one connecting electrode **750** and the bus bar electrode **710**, and another distance between another connecting electrode **750** and the bus bar electrode **710** are the same each other), the length of the connecting electrodes **750** can be minimized. Considering a tolerance (or a margin of error), the angle between the second region **753** with the first region **751** may be in a range of about 40 to about 50 degrees. Other angles may be used.

The first region **751** of the connecting electrode **750** has intersections **770** with the plurality of the second finger electrodes **760**. The width of the first region **751** may increase as the number of the second finger electrodes **760** connected to the connecting electrodes **750** increases. That is, as the number of the intersections **770** with the second finger electrodes **760** accumulates, the cross section of the connecting electrodes **750** increases, either gradually or in steps. Since the cross section or the thickness of the connecting electrode **750** is adjusted as discussed above, the resistance by the connecting electrodes **750** can be maintained below a predetermined value, regardless of the number of the second finger electrodes **760** connected to the connecting electrodes **750**. That is, the first region **751** may have a cross section decreasing as a distance from the bus bar **710** increases. Although not required, the first region **751** of the connecting electrode **750** may be parallel to the bus bar electrode **710**, while the second region **753** of the connecting electrode **750** is non-parallel to the bus bar electrode **710**.

In addition, the second finger electrodes **760** connected to the connecting electrode **750** may be bent at a portion adjacent to the intersections **770** with the connecting electrodes **750** in order to shorten the path formed by the second finger electrodes **760** to the connecting electrodes **750**. In this instance, in order to minimize the path, a bent angle may be about 40 to about 50 degrees (for example, 45 degrees), as discussed above.

FIG. **9** is a plan view of a front electrode according to still another embodiment of the invention. In the embodiment shown in FIG. **9**, finger electrodes **830** are directly connected to connecting electrodes **820** or a bus bar electrode **810**. In this instance, two connecting electrodes **820** are connected to one bus bar electrode **810**. The connecting electrodes **820** may be inclined with respect to the bus bar electrode **810** toward the finger electrodes **830** in a range that lengths of the finger electrodes **830** are not too short. Bent angles, the lengths, and widths of the connecting electrodes **820** may be adjusted considering an amount of a metal paste that is used for forming the front electrode and the efficiency of the solar cell due to an area of the light incident surface.

Unlike the embodiment of the invention described in referring to FIG. **7** and FIG. **8**, the finger electrodes **830** are not bent in the embodiment described referring to FIG. **9**. Thus, the finger electrodes **830** (specifically, the finger electrodes **830** connected to the connecting electrodes **820**) may have a stripe shape. In this instance, because the connecting electrodes **820** are inclined with respect to the bus bar electrode **810**, and are bent toward the finger electrodes **830**, the length of the finger electrodes **830** can decrease.

Instead of removing the end of the bus bar electrode **810**, the connecting electrodes **820** are connected to the finger electrodes **830**. Thus, the shading loss due to the bus bar electrode **810** can be reduced or prevented, and the metal paste for forming the electrodes can be reduced. Also, considering a possibility of short-circuit at one of the connecting electrodes **820**, a bridge electrode **850** connecting both of the connecting electrodes **820** may be included as an auxiliary electrode. In addition, the cross section of the connecting electrodes **820** may gradually decrease as the distance from the bus bar electrode **810** increases, considering the number of the finger electrodes **830** that are connected to the connecting electrodes **820** is smaller as the distance from the bus bar electrode **810** increases. The cross section of the connecting electrodes **820** may be adjusted by controlling the width or the thickness of the connecting electrodes **820**.

In embodiments of the invention, the bridge electrode **850** and the connecting electrodes **820** may have an A shape arrangement. Also, when a plurality of bridge electrodes **850** are used, lengths of the plurality of bridge electrodes **850** may be different. Additionally, increase in the cross section of the connecting electrode **820** may produce steps that face towards the outside (i.e., face towards the finger electrodes **830**).

According to the embodiments of the invention, by improving a pattern of a front electrode, the shading loss due to the front electrode formed on the light incident surface of the solar cell can be reduced, and thus, the efficiency of the solar cell can be enhanced. Also, the material cost for forming the front electrode can be also reduced.

Certain embodiments of the invention have been described. However, the invention is not limited to the specific embodiments described above; various modifications of the embodiments are possible by those skilled in the art to which the invention belongs without departing from the scope of the invention defined by the appended claims. Also, modifications of the embodiments should not be understood individually from the technical principles or prospects of the invention.

What is claimed is:

1. A solar cell comprising:

a photoelectric conversion layer; and

a front electrode on the photoelectric conversion layer, wherein the front electrode comprises:

a bus bar electrode;

at least one first finger electrode directly connected to the bus bar electrode;

a plurality of connecting electrodes extending from one end of the bus bar electrode and having a width smaller than a width of the bus bar electrode, wherein the plurality of connecting electrodes includes portions that are spaced apart from each other to form a space therebetween;

at least one second finger electrode connected to at least one of the plurality of connecting electrodes;

an auxiliary electrode formed at the space between the portions of the plurality of connecting electrodes; and

a ribbon on the bus bar electrode,

wherein the plurality of connecting electrodes and the auxiliary electrode are positioned near one end of the ribbon, are positioned in a longitudinal direction of the ribbon, and extend adjacent to an edge of the photoelectric conversion layer parallel to the at least one first finger electrode or the at least one second finger electrode at a space between the one end of the ribbon and the edge of the photoelectric conversion layer,

wherein the at least one second finger electrode comprises a plurality of second finger electrodes connected to one of the plurality of connecting electrodes,

wherein the plurality of connecting electrodes have a cross section varying at intersections of the plurality of connecting electrodes and the plurality of second finger electrodes so that the cross section gradually decreases as a distance from the bus bar electrode increases and as a distance from the edge of the photoelectric conversion layer decreases, and

wherein the auxiliary electrode extends in a direction crossing the at least one first finger electrode or the at least one second finger electrode.

2. The solar cell according to claim **1**, wherein the at least one second finger electrode comprises a plurality of second finger electrodes connected to the at least one of the plurality of connecting electrodes, and

the plurality of connecting electrodes have a cross section larger than cross sections of the at least one first finger electrode and the plurality of second finger electrodes.

3. The solar cell according to claim **1**, wherein the auxiliary electrode comprises an auxiliary bus bar electrode extending from the bus bar electrode between the plurality of connecting electrodes and having a width smaller than the width of the bus bar electrode.

4. The solar cell according to claim **3**, wherein the auxiliary bus bar electrode is spaced apart from the plurality of connecting electrodes and the at least one second finger electrode.

5. The solar cell according to claim **3**, further comprising:

a third finger electrode connected to the auxiliary bus bar electrode and being nearer to an edge of the solar cell than the at least one first and the at least one second finger electrodes.

6. The solar cell according to claim **5**, wherein the third finger electrode includes a part connected to the auxiliary bus bar electrode and bent towards the bus bar electrode, and

the auxiliary bus bar electrode and the third finger electrode form a Y shape.

7. The solar cell according to claim **5**, wherein the third finger electrode is parallel to the at least one first finger electrode.

8. The solar cell according to claim **1**, wherein the plurality of connecting electrodes comprise a first region having an intersection with the second finger electrode and a second region being bent towards the bus bar electrode.

9. The solar cell according to claim **8**, wherein the first region has a cross section that gradually decreases as a distance from the bus bar electrode increases.

10. The solar cell according to claim 1, wherein the plurality of connecting electrodes are inclined with respect to the bus bar electrode.

11. The solar cell according to claim 10, wherein the plurality of connecting electrodes and the bus bar electrode form a Y shape.

12. The solar cell according to claim 10, wherein the plurality of connecting electrodes have an angle of about 40 to about 50 degrees with respect to the bus bar electrode.

13. The solar cell according to claim 1, wherein the at least one second finger electrode comprises a plurality of second finger electrodes connected to the at least one of the plurality of connecting electrodes, and

the plurality of second finger electrodes have a stripe shape.

14. The solar cell according to claim 1, wherein the space between the plurality of connecting electrodes has an opening, or has a portion which is open towards an outside.

15. A solar cell comprising:

a photoelectric conversion layer; and

a front electrode on the photoelectric conversion layer, wherein the front electrode comprises:

a bus bar electrode;

at least one first finger electrode directly connected to the bus bar electrode;

a plurality of connecting electrodes extending from one end of the bus bar electrode and having a width smaller than a width of the bus bar electrode, wherein the plurality of connecting electrodes includes portions that are spaced apart from each other to form a space therebetween;

at least one second finger electrode connected to at least one of the plurality of connecting electrodes;

an auxiliary electrode formed at the space between the portions of the plurality of connecting electrodes;

at least one third finger electrode connected to the auxiliary electrode in a direction crossing the auxiliary electrode;

a ribbon on the bus bar electrode;

wherein the plurality of connecting electrodes, the auxiliary electrode and the at least one third finger electrode are positioned near one end of the ribbon, are positioned in a longitudinal direction of the ribbon, and extend adjacent to an edge of the photoelectric conversion layer parallel to the at least one first finger electrode or the at least one second finger electrode at a space between the one end of the ribbon and the edge of the photoelectric conversion layer, and

wherein the auxiliary electrode extends in a direction crossing the at least one first finger electrode and the at least one second finger electrode.

16. The solar cell according to claim 15, wherein the at least one second finger electrode comprises a plurality of second finger electrodes connected to one of the plurality of connecting electrodes, and

wherein the plurality of connecting electrodes have a cross section varying at intersections of the plurality of connecting electrodes and the plurality of second finger electrodes so that the cross section decreases at the intersections as a distance from the bus bar electrode increases and as a distance from the edge of the photoelectric conversion layer decreases, and each of portions between the cross sections has a uniform cross section.

* * * * *